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INFLUENCE OF EXTRUSION CONDITIONS ON NUTRITIONAL COMPOSITION OF RICE-BAMBARA GROUNDNUT COMPLIMENTARY FOODS

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Abstract
In this study, multivariate analysis of the relationship between extruder barrel temperatures (100-140^{o}C), initial feed moisture level (15-25%) and bambara groundnut flour (8-24%) content during twin-screw extrusion of rice-bambara groundnut blends for the production of complimentary food was investigated. Response surface methodology (RSM) and central composite experimental design (CCD) was used for the study. Twenty different blends were formulated based on CCD and extruded in a twin-screw extruder. Extruded samples were analyzed for nutritional quality using standard procedures and data fitted into a regression model. Results indicated significant variation among samples due to the process variability, with protein ranging between 16.99 and 27.36%, calorie value 391.14 and 397.99kcal/100g and Fe 10.1 and 13.02 mg/g sample. The fitted models for the prediction of linear, square and interaction relationships between the process and dependent variables were also significant ($p \leq 0.05$), adjusted coefficient of determinations ($R^2_{adjusted}$) > 90% and non-significant ($p \leq 0.05$) lack-of-fit. Optimum process conditions of 120^{o}C barrel temperature, 20g water/100g flour, and 22.4g bambara groundnut/100g flour were found to produce extruded complimentary foods having 21.66% protein, 394.33kcal/100g calorie, 1.34% fibre, 12.12mg/100g Fe and 25.81mg/100g Ca with a combined desirability function of 0.9102. The high protein of over 20% and 394.33kcal/100g calorie values are within the recommended values for normal growth and development of weaning and school children and therefore could be recommended for mitigating protein-energy malnutrition in developing countries, while the fitted models could be used in engineering modeling of extruder for food processing and new product development.

Keywords: Rice, Bambara Groundnut, Multivariate Analysis, Extrusions, Complimentary Food

1. Introduction

Rice (*Oryza sativa* L.) is one of the world's leading food crops. It is a strategic food security commodity in Nigeria as its production, processing, consumption and marketing challenges are key food and nutrition security priority for successive governments. Rice consumption has increased from 3kg per person per year in the 1960s to an average of 40kg per person per year with urban consumption exceeding 47kg/person/year in 2010 (NRDS, 2010; CBN, 2010). Poor postharvest practices and technologies result in significant quantities of broken grains during milling (Manful *et al.*, 2004) and lead to poor market values. Although the price of milled whole grains is much higher than that of broken grains, flour and flour-based products made from broken kernels are competitively priced (Kadan *et al.*, 2001; 2003; Kadan and Ziegler., 1989). Combined with its unique characteristics such as bland taste, attractive white color, hypoallergenicity, high expansion during extrusion and ease of digestion, and high calcium content, rice flour has become an attractive ingredient in the manufacture of new cereal-based products (Kadan *et al.*, 2001; Danbaba, *et al.*, 2016). But nutritionally, rice protein like that of most cereal grains is inadequate and deficient in essential amino acid lysine, therefore, it normally needs to be improved upon by complementing with food materials rich in lysine (Iwe, *et al.,* 2001). Food legumes have been proven to be comparatively rich in lysine and their

combination with cereals provides an ideal source of dietary protein. The use of low cost, lesser known legumes for this purpose has been one of the most suitable channels for addressing protein-energy-malnutrition in developing countries (Iwe, 2001; Iwe, *et al.,* 2004).

Bambara groundnut (*Vigna subterranean* L. Verdc) is an indigenous African crop, with high nutritive value (65% carbohydrate and 18% protein) (Baryel, 2001). It is, therefore, an important source of protein for the poor who cannot afford animal protein, in West Africa (Doku, 1995; Kouassi and Zoro, 2010; Dansi *et al*., 2012). Although, bambara groundnut (BGN) is deficient in sulphur-containing amino acids (Azam-Ali *et al*., 2001), some genotypes contain higher amounts of methionine and lysine than is found in other legumes (NRC, 2006). Utilization of the crop is limited to local foods. Therefore, its blend with rice for the production of ready-to-eat cereal through extrusion will facilitate increased use of the crop. Advancement in food processing operations has provided for processors with diverse technologies and techniques for the production of wholesome, nutritious and hygienic products. Extrusion cooking (EC), a high temperature short time (HTST) cooking is one of such technologies. Application of high temperature short time EC requires critical adjustment and setting of the multivariate production process parameters both for the machine and raw materials to be able to produce the desired product having required quality level. Because food materials are biochemical products, when subjected to EC they may undergo both physical and chemical changes (Akdogan, 1999; Ilo *et al.,* 1996; Iwe *et al*., 2004). These changes often result in new food product with new functional, nutritional and sensory qualities (Bryant *et al.,* 2001). The knowledge of changes in extruder operating variables such a screw speed, ingredients moisture content and composition, die size, barrel temperature, to mention a few, may therefore provide necessary information for the prediction of what fraction of food materials will undergo specific change during EC and the possible effect on the quality of the products (Ilo *et al*, 1999, Bryant, *et al*., 2001). There is therefore the need to evaluate the effect of different extrusion variables on the quality characteristics of products if new raw materials such broken rice fractions and bambara groundnut are to be extruded, and optimize these process variables for optimal product quality.

The objective of this study was to evaluate the multivariate mathematical relationships between extrusion cooking parameters [barrel temperature (A), initial raw material moisture level (B) and bambara groundnut feed composition (C)] and nutritional quality (proximate and minerals) of twin-screw extruded complimentary foods. Others are to determine the optimum process conditions that will produce high rank acceptable nutritious breakfast cereals using EC technology and designed experiment (DOE) and optimize EC temperature (A), initial feed moisture (B) and bambara groundnut (BGN) feed composition (C) for optimum nutritional composition of the complimentary foods that will meet the daily requirement of weaning chieldren.

2. Materials and Methods

2.1 Materials and pretreatment

Broken rice fractions from the milling of improved rice variety (FARO 52) with amylose content of 29.34±0.61% was obtained from National Cereals Research Institute (NCRI), Badeggi, Nigeria, while BGN (white seed type) was purchased from Bida modern market, Bida, Niger State, Nigeria. Rice and BGN samples were manually cleaned, sorted and milled into flour using a locally fabricated attrition mill and sieved to pass through 150µm laboratory sieve (Brabender

OHG Duisburg). Twenty (20) different blends of rice-RBG were formulated to contain different levels of BGN, and the moisture content was adjusted to fall between 15 and 24% (w/w) by spraying with a calculated amount of water (Eqn. 1) (Ascheri, 2010). Feed materials were allowed to stand for 3h to equilibrate at room temperature (30±2^{o}C) prior to extrusion.

$$\text{Amount of water to be added (g)} = \frac{(M_f - M_i)x\, S_w}{100 - M_f} \tag{1}$$

where: M_f = Final moisture content, M_i = Initial moisture content and S_w = Sample weight (g)

2.2 Extrusion cooking (EC) exercise

A co-rotating twin-screw extruder (SLG 65 Twin-Screw Extruder, Jinan Saibainuo Technology Development Co. Ltd, China) powered by 16hp motor and operating at 300 rpm screw speed, 20:1 length to diameter barrel ratio, 30 mm screw diameter, 30 kg/h feed rate obtained after series of trial experiments, and barrel temperature set at 100 – 140^{o}C was used to extrude the formulated samples. At a steady state, samples were collected and processed for analysis (Danbaba *et al*., 2016, Danbaba *et al*., 2017) by pulverization and cutting 100mm lengths of each extruded formulation.

2.3 Experimental design

Response surface methodology (RSM) in 3-factors (barrel temperature, moisture composition and BGN feed composition), 5-levels (-α, -1, 0, +1, +α) central composite rotatable design (CCRD) was used to formulate the blends and study the effect of the extrusion variables on the proximate and mineral compositions. Preliminary experiments results (not presented) define the variable range to lie between 100 – 140^{o}C for extrusion barrel temperature (A), 15 – 25% feed moisture (B) and 8 – 24% BGN feed composition (C). These variables were coded to lie at ±1α for the factorial points, 0 for the centre points and ±1α for axial points. These were calculated as a function of the range of interest of each natural variable as obtained during the preliminary experiment and the coded and un-coded variables are presented in Tables 1 (coded) and 2 (un-coded). The experiments were randomized to maximize the effects of unexplained variability in the observed responses due to extraneous factors, while five replicates at the centre of the design were used to allow for estimation of pure error sum of square and lack-of-fit. One-way analysis of variance (ANOVA) was conducted ($p \leq 0.05$) to determine significant of the models and difference among the mean treatment combinations. 3D surface plots were used to visualize the relationship between dependent and independent variables using Minitab software by plotting two independent variables against a response variable, holding the third independent variable constant.

2.4 Extrusion cooking process

The EC was performed using a co-rotating twin-screw extruder (SLG 65, Jinan Saibainuo Technology Development Company Ltd, China) powered by 16hp motor with an operating screw speed range of 0 to 300rpm, length to diameter ratio of barrel was 20:1, while the diameter of the screw was 30mm. The formulations were introduced manually into the feeding zone through a conical fed hopper at the rate of 30 kg/h while avoiding accumulation of material. When the flow was steady, samples were collected, dried and packaged before analysis.

Table 1: Codification of the independent variables (barrel temperature, initial feed moisture and feed composition) used for the construction of the response surface design

Levels	Independent variables		
	X_1	X_2	X_3
-α (-1.682)	86	12	2.6
Low (-1)	100	15	8
Medium (0)	120	20	16
High (+1)	140	25	24
+α (+1.682)	154	28.4	29.5

X_1 = Barrel temperature (ºC), X_2 = feed moisture content (%), X_3 = composition of bambara groundnut (%), Level of each variable was established based on a preliminary extrusion. The distance of the axial points from the centre point was ± 1.682, and calculated from Eqn. $\alpha = (2^n)^{1/4}$ where n is the number of variables.

Table 2: Outline of experimental design with variables in their coded and un-coded forms

Run No	Coded variables			Independent variables		
	X_1	X_2	X_3	X_1 (ºC)	X_2 (%)	X_3 (%)
1	-1	-1	-1	100	15	8
2	1	-1	-1	140	15	8
3	-1	1	-1	100	25	8
4	1	1	-1	140	25	8
5	-1	-1	1	100	15	24
6	1	-1	1	140	15	24
7	-1	1	1	100	25	24
8	1	1	1	140	25	24
9	-1.68	0	0	86	20	16
10	1.68	0	0	154	20	16
11	0	-1.68	0	120	12	16
12	0	1.68	0	120	28.4	16
13	0	0	-1.68	120	20	2.6
14	0	0	1.68	120	20	30
15	0	0	0	120	20	16

X_1 = Barrel temperature, X_2 = Feed moisture content, X_3 = Feed cowpea composition. Duplicate runs were carried out at all design point except at the centre point where five measurements were carried out and average recorded. The experimental runs were randomized.

2.5 Weaning foods preparation and nutritional analysis

Extruded samples (50g each) were pulverized and mixed with water (20 ml) to produce gruel that can be taken as instant weaning gruel. The mixed gruels were then evaluated for proximate and mineral composition using standard procedures. Moisture content of samples was determined by direct drying method, where 10g of sample was dried to a constant level in an oven at 60ºC for 24 h (AOAC, 1990). For ash content, 2g of sample powder was incinerated in a muffle at 550ºC for 4 h; the fat content was determined using Soxhlet method. For protein analysis, samples were digested by heating in 10 ml concentrated sulfuric acid and 8g digestion tablet ($8K_2SO_4$:$1CuSO_4$). After digestion, the mixture was made alkaline and ammonia released was collected in 2% boric acid solution and titrated against standard hydrochloric acid. Total nitrogen was determined and protein estimated by multiplying the amount of nitrogen with conversion factor 6.25 (AOAC, 1990). Carbohydrate was determined by difference, where the amount of moisture, crude fibre, protein, fat and ash were subtracted from 100 (% Carbohydrates

= 100 – (%Moisture + %Protein + %Lipid + %Ash), and the result considered as carbohydrate (AOAC, 2003). The Atwater calorie conversion factor was used to calculate caloric value where the energy values of 17kJ/g (4.0kcal/g) for protein, 37kJ/g (9.0kcal/g) for fat and 17kJ/g (4.0kcal/g) for carbohydrates (FAO, 2003) was used for conversion. Mineral content was determined by atomic absorption spectrophotometer (Varian Vista, Victoria, Australia) (AOAC, 2003). All analysis was carried out in triplicates.

2.6 Optimization and desirability analysis

Simultaneous optimization of the multiple responses (proximate and mineral compositions) was carried out to locate optimum combination of A, B and C that will simultaneously satisfy the target requirement placed on each response and factors (meeting daily nutrient requirement for complimentary foods). The goals of the experiment were to maximize protein, calorie value, and essential minerals in the final products. Goals (None, Maximum, Minimum, Target or Range) for all the independent variables and dependent variables were set and combined into one desirable function (*DF*) to be able to simultaneously optimize the responses where individual goals were combined into a single function to find the common solutions (Anuar *et al.*, 2013; Gupta *et al.*, 2014). Predictive model of each of the response variables were used to obtain individual desirability function (*dfi*) level (Eqn. 2) which were utilized for calculating a total desirability (DF) (Eqn. 3). *dfi* was based on a numerical range of 0 (minimum) - 1 (maximum) desirability, where if response value is at its desired goal or target, its desirability function (*dfi*) is equal to 1, and if it is outside the acceptable range, *dfi* = 0.

$$dfi = (U - \alpha)^{wi},\ \alpha \leq U \leq \beta \quad (2)$$

$(\beta - \alpha)$, $dfi = 1$, $U > \beta$, $dfi = 1$, $U < \alpha$

where: α and β are the lower and higher response values respectively obtained from *i* responses, while *wi* is the importance level. The scores of individual desirability to the levels required for each dependent variable are combined with the *DF* function through its geometric mean for all different values of df_i. *DF* therefore was then calculated as:

$$DF = [dfiV_1^1 \text{ x } dfiV_2^2 \text{ x } dfiV_3^3 \ldots .dfi_n]^{1/n} \quad (3)$$

where: $0 \leq V_i \leq 1$ (i = 1, 2, 3, . N), $\sum_{t-1}^{n} V_i = 1$, df_i is the desirability of response U_i (i = 1, 2, 3…… N) and v_i are the importance of responses, thereby assessing the levels of predictor variables that produce the most desirable expected responses (Khodadoust and Ghaedi, 2013; Neto, *et al.*, 2017).

2.7 Statistical Analysis

Because of the need to obtain linear, quadratic and interactive relationships between the process variables considered and the response variables, the data obtained from the laboratory analysis were fitted to a second order polynomial equation (Eqn. 4) and optimum parameters defined using process optimizer of Minitab statistical software version 17. From the resulting values, for each of the response variable, the coefficients of the polynomial equation (β_o, β_i and β_{ij}) were evaluated and the equation simplified based on the influence of the factors on the final response.

$$Y = f(y) = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i=1}^{k} \cdot \sum_{i=1}^{k} \beta_{ij} X_i X_j + \varepsilon \quad (4)$$

where: Y is the predicted response (proximate and mineral compositions) used as a dependent variable, k is the number of independent variables considered in the experiment; β_o constant coefficient and β_i, β_{ij} and β_{ii} are the coefficient of linear, interaction and square terms respectively, while ε is the random error term. To validate whether the fitted models provide an adequate approximation to the real system, analysis of the coefficient of determination (R^2) and adjusted coefficient of determination (R^2_{adj}) were carried out (Eqns 5 and 6 respectively).

$$R^2 = 1 - \frac{\text{SSR}}{\text{SSM} + \text{SSR}} \quad (5)$$

$$R^2_{adj.} = 1 - \frac{\text{n}-1}{\text{n}-\text{p}} (1 - R^2) \quad (6)$$

where: *SSR* is the sum of squares residual, *SSM* is the sum of squares model, *n* is the number of experiments and *p* is the number of predictors in the model not counting the constant term.

Probability value (*p*-value) of the Analysis of variance (ANOVA) was also used to check for the significance of each factor and interaction between the factors. The smaller the *p*-value ($p \leq 0.05$), the more significant is the corresponding coefficients. To determine the significance of replication error as compared to model error, lack-of-fit test was conducted. The *p*-value ($p \leq 0.05$) was then used to measure whether the lack-of-fit is statistically significant or otherwise at the described level of probability. Non-significant lack-of-fit was considered desirable.

3. Results and Discussion

The results presented in Tables 1 and 2 are the independent variables (X_1, X_2 and X_3) in there coded levels based on CCRD and the experimental design matrix for the formulations and combination with the other variables respectively. The variable ranges (Table 1) were blended based on a five-level-three-factor into 20 experimental runs (Table 2) based on the calculation, $N = 2^n + 2_n + N_c$, where *N* is the total number of experimental runs and *n* is the number of variables which in this experiment is $2^3 + (2 \times 3) + 6 = 20$ as presented in Table 2. The 20 runs consist therefore of 8 factorial points, 6 axial and 6 replications at the center points. The mean experimental (OBS) and predicted (PRD) values of the proximate and mineral analysis of the extruded samples are given in Tables 3 and 4 respectively. The results of the proximate analysis indicated that the moisture ranges from 0.1 and 1.3% moisture, 0.21 and 0.85% for lipid, 16.15 and 27.36% for protein, 0.73 and 1.77% fibre, 0.16 and 1.40% ash, 69.5 and 81.57% carbohydrate and 391.14 and 397.99 kcal/100g energy value (Table 3), while minerals ranges from 10.6-14.25 for Mg, Mn = 4.36-7.03, Fe = 10.01-13.02, Cu = 2.36-4.61 and Ca = 23.09-30.14mg/100g (Table 4). This variation is an indication of the effects of variability in the formulation composition, initial moisture content and extrusion temperature on the proximate and mineral composition. These variations do not show any specific pattern, and therefore will require optimization to attain optimum levels.

When the data in Tables 3 and 4 were subjected to regression analysis and analysis of variance, the estimated regression coefficient (β_{ij}), p-value, lack-of-fit test ($p \leq 0.05$), R^2 and adjusted R^2 for

proximate and mineral composition of the extruded complimentary foods were obtained and are also presented in Tables 5 and 6 respectively for proximate and mineral compositions. From ANOVA results, it is confirmed that the regression models from which the coefficients were predicted are significantly ($p\leq.05$) suitable for the prediction of the relationship between the independent and response variables since there is a significant ($p\leq0.05$) regression coefficients, low residual values (deviation), non-significant lack-of-fit ($p\leq0.05$) with satisfactory coefficients of determination (R^2) of 0.992, 0.972, 0.996, 0.983, 0.819, 0.997 and 0.991 for moisture, protein, lipid, ash, fibre, carbohydrate and calorie respectively (Table 5) and 0.961, 0.974, 0.954, 0.926, 0.978, and 0.991 respectively for Mg, Mn, Fe, Cu, Zn and Ca respectively (Table 6). The close relationship between the observed and predicted values in this study is indicative of precision of the regression results (Tables 3 and 4).

The three-dimensional (3D) response surface plots representing each response developed as simultaneous function of three of the independent variables and holding one constant (BRT=A, FMC=B and FBC=C) according to their significance to the responses and are indicated in Figures 1-2 for moisture, fat, protein, fibre, ash, CHO and calorie respectively, and Figure 3-4 for mineral composition. A convex response surface plot (Figure 1a and b) suggested that there is a well-defined optimal level of the moisture and fat content under the interactive conditions of feed moisture content (FMC) and feed BGN composition (FBC). While symmetrical plot and flat near the optimal (Figure 1c) indicates that the optimal value may not vary widely from single variable condition (Rao *et al.*, 2006; De-Lema *et al.*, 2010).

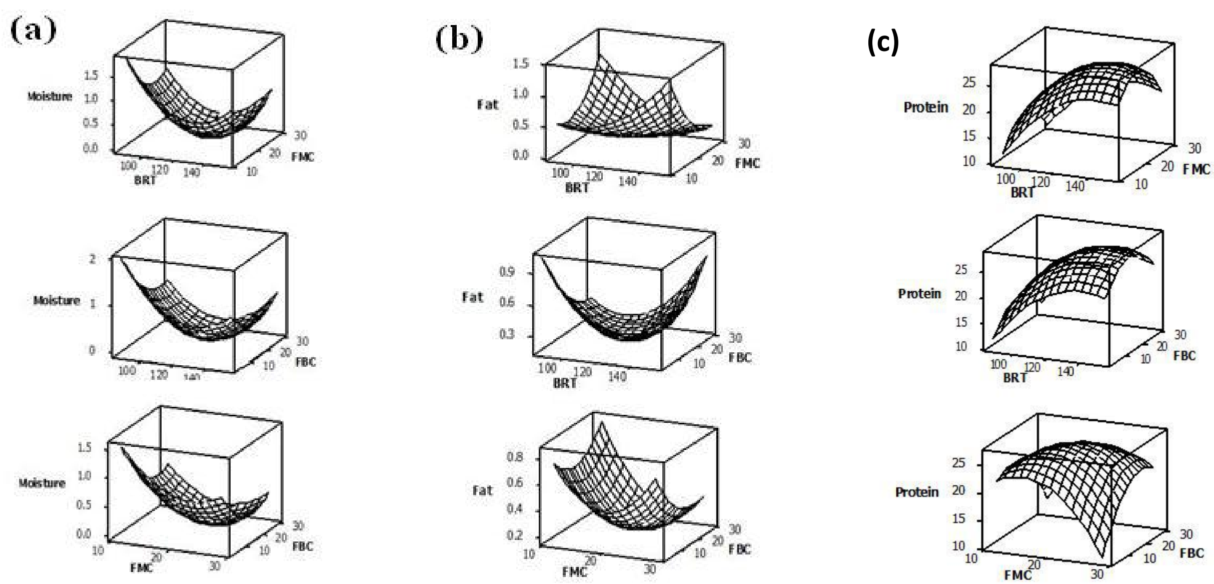

Figure 1: Effect of barrel temperature (BRT), feed moisture content (FMC) and feed bambara groundnut composition (FBC) on the moisture (a), fat (b) and protein (c) content of extrudates

Table 3: Experimental design, observed and predicted proximate composition of rice-bambara groundnut extrudates

Run	Design points			Moisture (%)		Lipid (%)		Protein (%)		Fibre (%)		Ash (%)		Carbohydrate (%)		Energy (Kcal/100g)	
	X_1	X_2	X_3	OBS	PDT	OBS	PDT	OBS	PDT	OBS	PDT	OBS	PDT	OBS	PDT	OBS	PDT
1	100	15	8	1.30	1.28	0.53	0.50	20.11	20.19	1.77	1.78	0.66	0.65	76.93	76.74	392.93	392.62
2	140	15	8	0.71	0.70	0.66	0.63	26.86	26.93	1.58	1.57	1.40	1.48	69.50	69.37	391.38	391.14
3	100	25	8	0.83	0.81	0.79	0.76	16.15	16.23	0.83	0.83	0.66	0.69	81.57	81.40	397.99	397.83
4	140	25	8	0.52	0.47	0.29	0.24	22.02	22.01	0.73	0.71	0.53	0.41	76.43	76.39	396.41	396.27
5	100	15	24	0.67	0.64	0.33	0.31	17.11	17.20	1.02	1.05	0.16	0.79	80.38	80.22	392.93	392.80
6	140	15	24	0.45	0.41	0.85	0.81	23.93	23.91	0.99	0.95	1.28	1.25	72.95	72.91	395.17	395.00
7	100	25	24	0.35	0.30	0.40	0.39	20.11	20.10	1.00	1.01	1.02	1.00	77.47	77.41	393.92	393.86
8	140	25	24	0.33	0.31	0.28	0.25	25.89	25.85	1.03	1.01	0.33	0.36	72.47	72.46	395.96	395.98
9	86.4	20	16	1.01	1.02	0.58	0.54	16.99	16.82	1.18	1.09	0.72	0.59	80.53	80.72	395.30	395.52
10	154	20	16	0.57	0.55	0.55	0.53	27.36	27.32	0.92	0.90	0.78	0.75	70.39	70.36	395.95	396.06
11	120	12	16	0.77	0.74	0.66	0.64	22.30	22.18	1.68	1.59	1.36	1.20	74.00	74.19	391.14	391.44
12	120	28.4	16	0.26	0.26	0.42	0.39	20.50	20.48	0.88	0.84	0.49	0.48	77.71	77.73	396.62	396.64
13	120	20	2.6	0.81	0.81	0.47	0.44	21.93	21.79	1.32	1.27	0.96	0.93	75.32	75.51	393.23	393.54
14	120	20	30	0.14	0.13	0.31	0.29	22.52	22.50	0.93	0.90	1.10	1.00	75.14	75.13	393.43	393.45
15	120	20	16	0.10	0.09	0.21	0.20	26.77	26.76	0.82	0.86	0.97	0.76	71.41	71.37	394.61	394.54
Mean	-	-	-	0.59	0.57	0.49	0.46	22.04	22.02	1.11	1.09	0.83	0.82	75.48	75.46	394.47	394.45

OBS = Observed, PRD = Predicted, X_1 = Barrel temperature, X_2 = Feed moisture content, X_3 = Feed composition. Duplicate runs were carried out all design point and average recorded. The experimental runs were randomized; all other extrusion conditions were held constant during the extrusion.

Table 4: Experimental design, observed and predicted mineral composition of rice-bambara groundnut extrudates

Run	Design points			Mineral composition (mg/100g)											
				Mg		Mn		Fe		Cu		Zn		Ca	
	X_1	X_2	X_3	OBS	PDT	OBS	PDT	OBS	PDT	OBS	PDT	OBS	PDT	OBS	PDT
1	100	15	8	11.96	12.06	5.69	5.59	11.03	10.99	2.36	2.36	4.17	4.24	26.11	25.99
2	140	15	8	13.04	13.19	5.66	5.72	13.02	12.88	3.41	3.43	5.08	4.91	26.11	26.55
3	100	25	8	12.36	12.57	5.43	5.54	11.01	11.03	4.61	4.61	5.42	5.34	28.01	27.89
4	140	25	8	13.10	12.84	4.37	4.23	12.06	11.90	4.61	4.62	4.46	4.54	30.14	30.08
5	100	15	24	11.52	11.94	5.02	5.28	10.21	10.09	4.18	4.18	4.06	3.94	26.76	26.61
6	140	15	24	13.51	13.46	6.11	6.12	11.11	10.80	3.36	3.36	5.06	5.10	27.00	26.91
7	100	25	24	12.23	12.24	5.38	5.44	12.34	12.20	4.36	4.35	5.46	5.59	25.87	25.58
8	140	25	24	12.86	12.92	4.62	4.84	12.11	11.90	2.46	2.46	5.38	5.27	27.60	27.51
9	86.4	20	16	10.60	10.24	4.36	4.22	12.02	12.05	3.82	3.82	5.02	5.00	27.08	27.38
10	154	20	16	11.62	11.76	4.86	3.83	13.01	13.38	3.15	3.14	5.21	5.29	29.47	29.47
11	120	12	16	13.41	13.12	6.12	6.05	10.01	10.24	2.72	2.71	4.44	4.53	25.11	25.20
12	120	28.4	16	13.01	13.08	5.03	4.94	11.00	11.18	3.84	3.84	5.62	5.59	27.05	27.28
13	120	20	2.6	14.16	14.12	6.42	6.52	11.32	11.38	4.50	4.49	4.02	4.06	26.85	26.88
14	120	20	30	14.25	14.07	7.03	6.77	10.26	10.61	4.20	4.21	4.41	4.43	24.96	25.23
15	120	20	16	13.96	14.00	6.04	6.07	11.56	11.49	4.16	4.16	4.00	3.99	23.09	23.04
Mean	-	-	-	12.77	12.75	5.48	5.41	11.47	11.48	3.72	3.71	4.79	4.78	26.75	26.77

OBS = Observed, PRD = Predicted, X_1 = Barrel temperature, X_2 = Feed moisture content, X_3 = Feed composition. Duplicate runs were carried out all design point and average recorded. The experimental runs were randomized; all other extrusion conditions were held constant during the extrusion

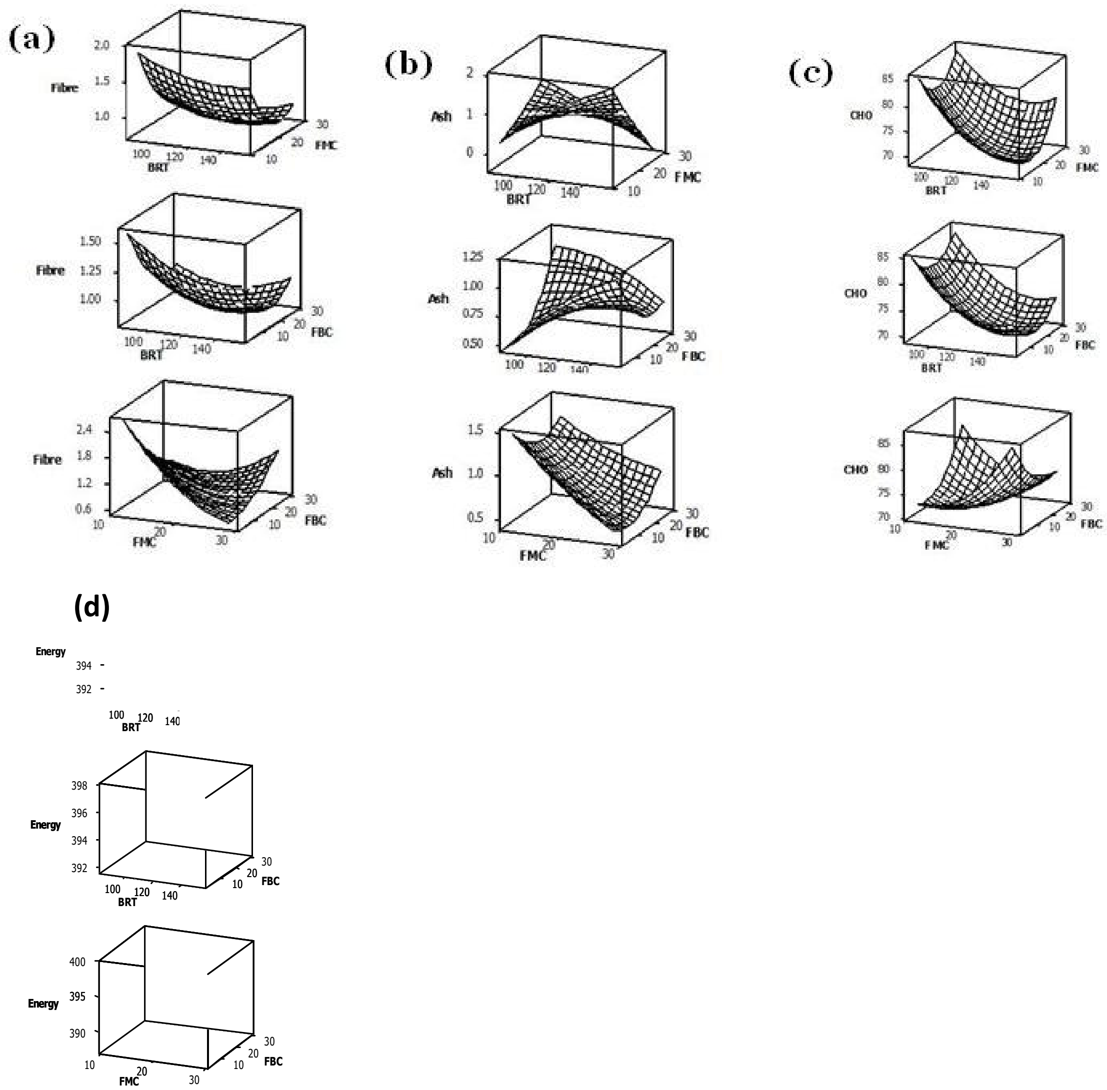

Fig. 2: Effect of barrel temperature (BRT), feed moisture content (FMC) and feed bambara groundnut composition (FBC) on the fibre (a), ash (b), carbohydrate (c) content and calorie value of extrudates

3.1 Multivariate analysis of the effects of extrusion on proximate composition

3.1.1 Moisture content (MC, %)

The coefficients for the linear terms of Eqn. 5 representing the relationship between independent variables and moisture (%) indicated that all the variables negatively affected final moisture content of the extruded samples, while the quadratic and interaction terms increased with increasing moisture content. This trend is depicted in Figure 1a.

$$MC = +16.4646 - 0.1765A - 0.3486B - 0.1742C + 0.0006A^2 + 0.0058B^2 + 0.0021C^2 + 0.0006AB + 0.0005AC + 0.0008BC \quad (R^2 = 0.989) \qquad (5)$$

The gradual decrease in moisture content at the linear level observed in this study is similar to the report of Badrie and Mellows (1991) and Hagenimmana *et al.,* (2006) who observed

increasing product moisture content as the feed initial moisture level increased. Increasing BRT reduced product moisture content, possibly due to flash of water at the die as the product was exiting the die. At high BRT, low moisture (10-14%) and mechanical shear, a high vapor pressure was created in the barrel and this increased the flash of moisture at the die thus reducing the product final moisture (Badrie and Mellows, 1991; Hagenimmana *et al.*, 2006).

3.1.2 Fat content (FC, %)

As given in Eqn. 6, it is clear that BRT and FBC negatively affected the lipid content at linear and interactive levels, while at quadratic level all the process variables positively increased the lipid content. From Figure 1b, increasing barrel temperature and FBC increased until till it reached an optimum level of 25% before decreasing. At high BRT, low FMC (Figure 1b) and shear in the extruder, the walls of flour granules ruptured and oil droplets combined to form macro droplets increasing lipid content, but decreased as the fat content complex formation with other feed compositions intensified. Wang *et al*. (1993) reported that starch or protein complex formation with lipids during extrusion may results in the variation of lipids at different process conditions.

$$FC = 3.72936 - 0.04731A + 0.01798B - 0.08364C + 0.00029A^2 + 0.00446B^2 + 0.0009C^2 - 0.00162AB + 0.00059AC - 0.00108BC \quad (R^2 = 0.972) \tag{6}$$

The presence of high protein from BGN flour created conducive conditions for the formation of lipid-starch and lipid-protein complexes (Guha and Ali, 2006), thereby reducing fat content of the final product as observed in this study.

3.1.3 Protein content (PC, %)

From Eqn. 7, feed moisture content (B) and FBC (C) positively affected the protein content, while increasing BRT (A) decreased product protein content. At quadratic level, all the variables negatively impacted protein, but at interactive level, the addition of BGN was the only factor that increased the protein content.

$$PC = -79.3305 + 1.1989A + 2.5676B - 0.0106C - 0.0041A^2 - 0.0767B^2 - 0.0255C^2 - 0.0024AB + 0.0429BC \quad (R^2 = 0.996) \tag{7}$$

From the response surface plot (Figure 1c) for BGN, it is clear that increasing feed bambara groundnut level, caused drastic and consistent increase of the protein content of the extrudates. However, at higher BGN (20-25%), additional increase caused only slight increase in protein and finally started to fall. The optimal protein content between 20-25% is sufficient if eaten by children and adults for satisfactory protein intake (Champell *et al*., 2008). The increase in protein content was significant at lower temperature and reached optimum before decreasing when it reached 120^{o}C. The decrease in protein at a higher temperature may be as a result of denaturization of protein molecules at higher temperature (Stanley, 1989; Sabota *et al.,* 2010).

3.1.4 Fibre content (FB, %)

The effect of the relationship between the response variables and fibre content is represented in Eqn. 8. All the variables negatively affected the fibre content at the linear level, all at square and interactive levels; they positively affected the fibre content. This indicates that initial feed

moisture, barrel temperature and addition of bambara individually reduces fibre content during extrusion, but when considered together they positively impacted fibre level.

$$FB = 9.077 - 0.03899A - 0.36344B - 0.19056C + 0.00012A^2 + 0.00503B^2 + 0.00125C^2 + 0.00022AB + 0.00019AC + 0.0057BC \quad (R^2 = 0.983) \tag{8}$$

The 3D surface plots showing the effects of the process variables on the fibre content of extrudates is represented by Figure 2a. The fibre content in this study decreased with increasing BRT and FMC, but increased with increasing FBC indicating significant contribution of the legume to fibre content of the extrudates. The slightly concave to flat surface plots (Figure 2a-c) may suggest that the optimum value may not vary widely from the single variable condition. There is a general accepted demand world over of the need to increase fibre content of foods including extruded products from the stand point of nutrition. The increase observed in this study therefore is advantageous nutritionally.

3.1.5 Ash content (AC, %)

The effect of the process variables on the ash content of the extrudates is represented by the second-order regression model (Eqn. 9). From the equation it is clear that at linear level, increasing any of the variables resulted in increased ash content, but at square and interaction levels, increasing X_1 resulted in decreased ash. Figure 2b is the 3D response surface of the relationship between ash and the process variables. At low BRT, FMC and addition of bambara groundnut the ash content significantly ($p \leq 0.05$) increased. This result is in agreement with that of El-Samahy *et al.* (2007) who observed significant increase in ash content of cactus-pear-cereal during extrusion. The ash content is the measure of the total amount of minerals present in food product.

$$ASH = -6.50356 + 0.08585A + 0.22716B + 0.01409C - 0.00008A^2 + 0.00108B^2 + 0.00113C^2 - 0.00276AB - 0.00057AC + 0.0011BC \quad (R^2 = 0.819) \tag{9}$$

3.1.6 Carbohydrate content (CHO, %)

The effect of process variables on the carbohydrate content of extrudates in coded forms is represented by En 10. At the linear level, both A and B negatively affected CHO, while at square level, all the variables positively affected the CHO, but only the interaction between B and C caused the reduction of CHO. Figure 2c is the 3D response plot of the effect of process variables on CHO content. Holding the substitution level of bambara groundnut at 16% and changing the BRT and FMC resulted in decreased CHO.

$$CHO = 169.844 - 1.157A - 2.346B + 0.209C + 0.004A^2 + 0.065B^2 + 0.022C^2 + 0.006AB - 0.047BC \quad (R^2 = 0.997) \tag{10}$$

Rice contains high composition of CHO (65-75%) and during extrusion at high temperature, starch undergo both structural and chemical transformations and complex formation with other components resulting in decreased level in the final product. During cooking of rice in excess or optimum amount of water, starch absorbs water, swell and gelatinize and become palatable, but under minimal moisture level and high temperature as in extrusion cooking, non-enzymatic

browning reaction between molecules of protein and reducing sugar from starch gelatinization resulting in decreased CHO content as observed in this study.

3.1.7 Calorie value (CAL, Kcal/100g)

The calorie value (energy) of food materials including extruded foods has long been recognized as the sum of energies from protein, fat, and carbohydrate. The effect of process variables on calorie value of the extruded foods is presented in Eqn. 11, while 3D surface plots is presented in Fig. 2d. The graph indicated varied impact of the variables on calorie value and therefore the need to optimize. Optimal calorie is required in foods for children and people with special requirements. Inadequate energy intake limit the potentials of individuals in many developing countries, while excess intake lead to high prevalence of obesity with its attendant complications across all socio-economic divides in both developed and developing countries, thus the need to optimize calorie value of foods for sufficient energy delivery.

$$CAL = 401.237 - 0.344A + 1.033B + 0.012C + 0.001A^2 - 0.007B^2 - 0.006C^2 + 0.006AC - 0.026BC \quad (R^2 = 0.987) \qquad (11)$$

At linear level, only barrel temperature affected calorie value negatively, while at square level, both initial feed moisture content and barrel temperature affected calorie. At interaction level, there was no significant impact of the interaction between the factors except feed moisture and feed BGN composition (Eqn. 11).

3.2 Multivariate analysis of the effects of extrusion on mineral composition

Minerals represent a micro portion of food, but are essential in food chemistry and nutrition. But, despite their importance for health and nutrition, little studies have examined mineral changes during extrusion cooking probably because of their stability in other food processing methods (Camire *et al.*, 1990; Singh *et al.,* 2007). Minerals are heat stable and unlikely to become lost in the steam distillate at the die (Singh *et al.*, 2007). In this study, the effect of process variables on the mineral content of rice-bambara groundnut extrudates was studied and their relationships are represented by the Eqns. 12-17 for Mg, Mn, Fe, Cu, Zn and Ca respectively.

The mean observed and predicted values for the mineral composition is presented in Table 4. The results indicated a significant ($p \leq 0.05$) variation in mineral composition based on the varied process factors combinations. Mg ranges from 10.6 – 14.25 (mean = 12.77), Mn 4.36-7.03 (5.48), Fe 10.01-13.02 (11.47), Cu 2.36-4.61 (3.72) and Ca 23.09-30.14 (26.75). The lowest and highest Mg were recorded at experimental conditions of A = 86.4, B = 20, C = 16 and A = 120, B = 20, C = 30 respectively. Mn content was lowest (4.36mg/100g) at A = 86.4, B = 20, C = 16 and highest (7.03mg/100g) at A = 120, B = 20, C = 30 respectively. In both Mg and Mn, decreasing barrel temperature (A) and feed BGN composition (B) resulted in decreased levels (Table 4).

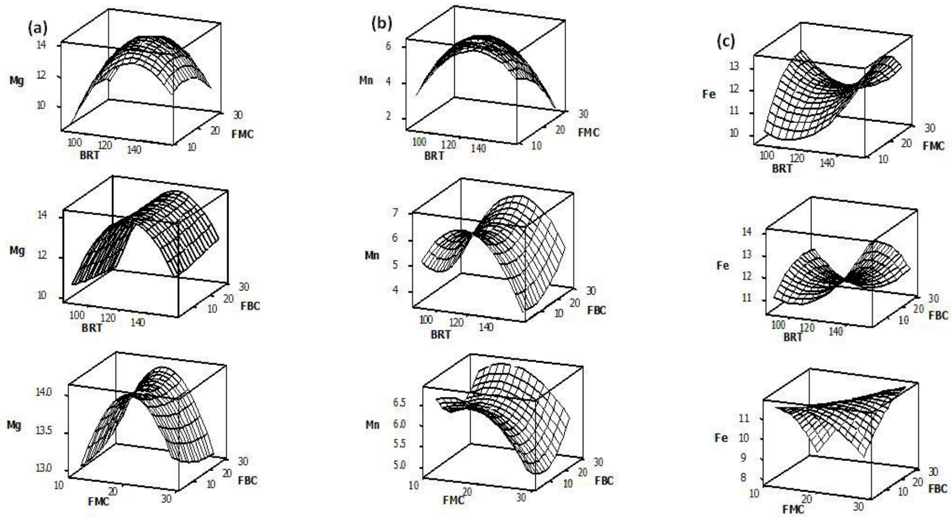

Figure 3: Effect of barrel temperature (BRT), feed moisture content (FMC) and feed bambara groundnut composition (FBC) on the magnesium (a), manganese (b) and iron (c) content of extrudates

Equations 12 to 17 are the representations of the relationships between the independent variables and the response variables in terms of Mg, Mn, Fe, Cu, Zn and Ca respectively. They demonstrate the linear, square and interactive effects of the experimental variables on the respective mineral composition. For Mg, increasing A and reducing B composition significantly ($p \leq 0.05$) increased Mg content of the extrudates at linear level, but at square level, increasing C and reducing A and B contents did not affect Mg retention content of the extrudate significantly ($p \leq 0.05$) (Eqn. 12).

$$Mg = -36.0975 + 0.6917A + 0.7826B - 0.0683C - 0.0027A^2 - 0.0127B^2 + 0.0005C^2 - 0.0021AB + 0.0006AC - 0.0013BC \quad (R^2 = 0.961) \qquad (12)$$

$$Mn = -26.6064 + 0.4818A + 0.6719B - 0.2513C - 0.0018A^2 - 0.0082B^2 + 0.0032C^2 - 0.0036AB + 0.0011AC + 0.0013BC \quad (R^2 = 0.974) \qquad (13)$$

Figure 4a-c is the 3D response plots of effects of process variables on Mg (Figure 4a), Mn (Figure 4b) and Cu (Figure 4c) respectively. Increasing barrel temperature significantly ($p \leq 0.05$) decreased Mg, but reached an optimum level before increasing as the temperature increased beyond 120°C (Figure 4a). The concave nature of the surface plots also indicated that optimum level of Mg is attainable under the considered process conditions.

While Mn was negatively affected by the addition of bambara groundnut at linear level (Eqn. 13). Increasing feed content of bambara groundnut resulted in decreased Mn level in final product. At extrusion conditions of A = 120, B = 12 and C = 16, Fe content was lowest (10.01mg/100g) and highest value was observed as A increased to 140°C, B to 15% and C decreased to 8%, indicating increasing Fe content as the extrusion temperature and moisture contents increased and reduced with increased feed composition. Similar trend is observed when critically examining the 3D response plot in Figure 4b.

$$Fe = 13.2497 - 0.1587A + 0.6052B + 0.0251C + 0.0011A^2 - 0.0111B^2 - 0.0028C^2 - 0.0026AB - 0.0019AC + 0.0128BC \quad (R^2 = 0.954) \tag{14}$$

From Eqn. 14, it is clear that increasing barrel temperature significantly ($p \leq 0.05$) reduced Fe content of extrudates and interaction between feed initial moisture content and temperature also negatively impacted Fe content. Alonso *et al*. (2000) and Danbaba *et al.* (2015) earlier reported significant variation in Fe composition of extruded pea and kidney bean seeds and rice-cowpea blends respectively and attributed these changes to possible wearing of metal component of the extruder at high moisture and temperature conditions. Similar accession was also held by Harper (1992) who reported that temperature between 105-150^{o}C and feed moisture content of 18-20%, there was a significant rise in Fe content of extrudates. The Fe content range of 10.01 to 13.02 mg/100g recorded in this study is worthy to note as most diets in many developing countries are deficient in Fe. Fe plays an important function in cellular metabolisms as essential component of enzymes, especially those associated with respiratory mitochondria for transport of oxygen to the tissues. Fe deficiency anemia is widely distributed malnutrition related diseases among children, adolescent girls and breast feeding mothers in Africa (Gehring, *et al*., 2011).

Cu increased significantly ($p \leq 0.05$) from 2.36 to 4.61 mg/100g as the barrel temperature increased from 100 to 120^{o}C, feed moisture from 15 to 20%, and feed BGN composition from 8 to 30%, indicating significant impact of increasing all the variables during extrusion on Cu content. Eqn. 15 represents the relationship between the independent variables in their coded form and Cu as a response.

Copper (mg/100g), Cu;

$$Cu = -25.4390 + 0.2347A + 1.0970B + 0.5712C - 0.0006A^2 - 0.0125B^2 + 0.0010C^2 - 0.0027AB - 0.0029AC - 0.0130BC \quad (R^2 = 0.926) \tag{15}$$

At linear level all the variables positively affected Cu content, but at quadratic level feed moisture content affected it negatively. All the variables negatively affected Cu response at interaction level (Eq. 15).

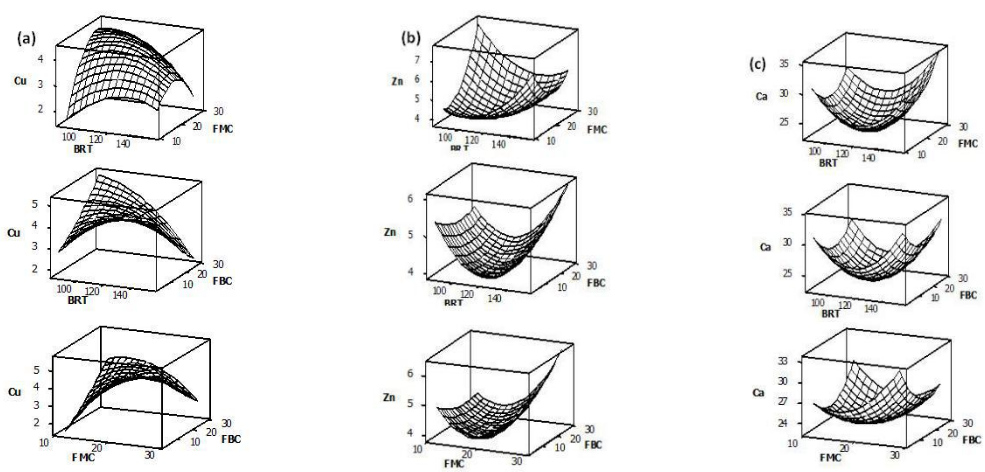

Fig.4: Effect of barrel temperature (BRT), feed moisture content (FMC) and feed bambara groundnut composition (FBC) on the cupper (a), zinc (b) and calcium (c) content of extrudates

Cu in human diet allows many critical enzymes to function properly and also maintaining the strength of skin, blood vessels, epithelial and connective tissue throughout the body. It also acts as both anti and pro-oxidants. As an antioxidant, it scavenges or neutralizes free radicals and help to reduce their damages, but as pro-oxidants, Cu promotes free radical damage and therefore may contribute to the development of Alzheimer's disease (Osredkar and Sustar, 2011). Highest Zn content (5.62 mg/100g) was observed at experimental conditions of A = 120, B = 28.4 and C = 16 and the lowest (4.0 mg/100g) at A = 120, B = 20 and C = 16 indicating significant ($p<0.05$) increase in Zn content as the moisture level increased from 20 to 28.4% (Table 4).

Zinc (mg/100g), Zn;

$$Zn = 16.7687 - 0.1788A - 0.1532B - 0.1904C + 0.0010A^2 + 0.0151B^2 + 0.0014C^2 - 0.0037AB - 0.0008AC + 0.0034BC \quad (R^2 = 0.978) \qquad (16)$$

At linear level, all the variables negatively impacted Zn and positively increased at square level (Eqn. 16). But at interaction level, only the interaction between feed moisture level and composition positively impacted Zn. Daily intake of Zn and Cu is required for the maintaining of steady metabolism because of lack of specialized storage system for the two microelements in the body (Rink and Gabriel, 2000; Araya, *et al*., 2006; Osredkar and Sustar, 2011). Optimizing Cu and Zn contents during for processing and maintaining dietary balance are critical in food and nutrition (Araya *et al*, 2006). For Ca, the least value (23.09 mg/100g) was recorded at 120°C barrel temperature, 20% feed moisture and 16% feed bambara composition, while the highest (30.14 mg/100g) was at 140°C, 25% and 8% barrel temperature, feed moisture and composition respectively (Table 4).

Calcium (mg/100g), Ca;

$$Ca = 111.824 - 1.187A - 1.877B - 0.180C + 0.005A^2 + 0.045B^2 + 0.017C^2 + 0.004AB - 0.001AC - 0.018BC \quad (R^2 = 0.991) \qquad (17)$$

This result indicated that when temperature and feed moisture increased, there is a resultant decrease in Ca while reducing feed bambara composition favored increased Ca. Harper (1990) reported increase in calcium content of extruded grits from 2.95 to 3.70 mg/100g. Calcium is essential for growth, bone formation, blood coagulation, milk formation, etc. Deficiency of Ca leads to rickets, *Osteomalacia* and *Osteoporosis*.

3.3 Validation of fitted multivariate regression models

The coefficients in the regression models (Eqns. 5-17) can be used to examine the significance of each term relative to the responses observed as coded values. Statistical analysis (Tables 5 and 6) for proximate and mineral compositions respectively showed that barrel temperature, feed moisture and feed composition all had a significant ($p\leq 0.001$) effect on the proximate and mineral composition of rice-bambara groundnut extruded foods. The interactions between the three factors were also found significant ($p\leq0.001$) (Table 5 and 6). It is important in RSM that significant model need to be tested to see if it provides an adequate approximation for application in natural condition. In this study, nature of the residual of the models and coefficient of determination (R^2 and adjusted R^2) (measure of how much the observed variability in the experimental value could be explained by the model) were considered as measure of adequacy. Additionally, test indicating the significance of the replicate error in comparison to the model

dependent error (lack-of-fit test) was also performed and it p-value used to check if it is significant or otherwise at the desired level of significance. The coefficients of the individual regression terms, analysis of variance, R^2 and adjusted R^2 and lack-of-fit test are therefore presented in Tables 5 (proximate) and 6 (minerals) respectively.

Table 5: Estimated Regression equation coefficients, analysis of variance (ANOVA), lack-of-fit p-values, R^2 and adjusted R^2 for proximate composition and energy values for response variables.

Coefficient	Moisture (%)	Lipid (%)	Protein (%)	Fibre (%)	Ash (%)	CHO (%)	Energy (Kcal/100g)
Constant	16.4646	3.72936	-79.3305	9.07700	-6.50355	169.844	401.237
Linear							
A	-0.1765**	-0.04731	1.1989**	-0.03899*	0.08585*	-1.157*	-0.344**
B	-0.3486**	0.01798**	2.5676**	-0.36344*	0.22716*	-2.346**	1.033*
C	-0.1742*	-0.08364	-0.0106**	-0.19056**	0.01409*	0.209*	0.012*
Quadratic							
A^2	0.0006*	0.00029*	-0.0041**	0.00012*	-0.00008*	0.004*	0.001**
B^2	0.0058**	0.00446*	-0.0767*	0.00503*	0.00108*	0.065*	-0.007*
C^2	0.0021*	0.00090*	-0.0255**	0.00125*	0.00113*	0.022*	-0.006*
Interaction							
AB	0.0006*	-0.00162*	-0.0024*	0.00022**	-0.00276*	0.006*	<0.001**
AC	0.0005*	0.00059*	-<0.0001*	0.00019*	-0.00057*	<0.001*	<0.001**
CB	0.0008*	-0.00108*	0.0429*	0.00570*	0.00108**	-0.047*	-0.026**
R^2	99.2	97.2	99.6	98.3	81.9	99.7	99.1
R^2_{adj}	98.9	95.9	98.3	97.5	73.7	98.8	98.7
Lack-of-fit	NS	NS	NS	NS	NS	NS	NS

$^aY = \beta_o + \beta_1A + \beta_2B + \beta_3C + \beta_{11}A^2 + \beta_{22}B^2 + \beta_{33}C^2 + \beta_{12}AB + \beta_{13}AC + \beta_{23}CB$; A = Barrel temperature, B = Feed Moisture content, C = feed blend composition, * and ** = significant at 5% and 1% level of probability respectively.

From the results the model terms are found to be significant ($p \leq 0.05$) for both proximate and mineral composition. Table 5 shows that R^2 and adjusted R^2 of proximate composition are 99.2, 97.2, 99.6, 98.0, 81.9, 99.7, 99.1% and 98.9, 95.9, 98.3, 97.5, 73.7, 98.8 and 98.7% respectively for moisture, lipid, protein, fibre, ash, CHO and calorie values. While that of mineral composition (Table 6) are 96.1, 97.4, 95.4, 92.6, 97.8, 99.1 and 89.2, 92.7, 87.1, 91.3, 93.7 and 97.4% for Mg, Mn, Fe, Cu, Zn and Ca respectively. Koocheki, *et al.* (2009) suggested that for a good fitted regression model, the R^2 should not be less than 80.0%, though Chauhan and Gupta (2004) opined that a value greater than 75.0% could satisfactorily explain the variability in a food based model. From this study, the values for both proximate and mineral composition indicated appropriateness of the fitted models to predict the relationship between the independent and response variables. Both the R^2 and adjusted R^2 are also close to 100%, indicating high ability of models to explain the variability observed in the responses due to the process variables (Lee and Wang, 1997; Zaibunnisa, *et al*., 2009). It is important to note that adding a variable to the model will always increase R^2, regardless of whether the variable is statistically significant or not, but no change in adjusted R^2. Thus, a large R^2 may not always imply adequacy of the model. For this reason therefore, it is more appropriate to use adjusted R^2 to evaluate the model adequacy (Koocheki, *et al*. 2009). Higher adjusted R^2 indicated that non-significant terms have not been included in the model as observed in this study. The non-significant ($p \leq 0.05$) lack-of-fit tests observed in both proximate and mineral compositions are indication of appropriateness of the model to navigate the domain of experimental conditions in their natural conditions.

Table 6: Estimated Regression equation coefficients, analysis of variance (ANOVA), lack-of-fit p-values, R^2 and adjusted R^2 for mineral composition in rice-bambaranut extrudates

Term	Mg	Mn	Fe	Cu	Zn	Ca
Constant	-36.0975*	-26.6064*	13.2497	-25.4390*	16.7687*	111.824*
Linear						
A	0.6917*	0.4818*	-0.1587	0.2347*	-0.1788*	-1.1870*
B	0.7826*	0.6719*	0.6052	1.0970*	-0.1523	-1.8770*
C	-0.0683	-0.2513*	0.0251	0.5712*	-0.1904*	-0.1800
Quadratic						
A^2	-0.0027*	-0.0018	0.0011*	-0.0006*	0.0010*	0.0050*
B^2	-0.0127	-0.0082	-0.0111	-0.0125*	0.0151	0.0450*
C^2	0.0005	0.0032	-0.0028	0.0010*	0.0014	0.0170*
Interaction						
AB	-0.0021	-0.0036*	-0.0026	-0.0027*	-0.0037*	0.0040*
AC	0.0006	0.0011	-0.0019*	-0.0029*	-0.0008*	-0.0010
CB	-0.0013	0.0013	0.0128*	-0.0130*	0.0034*	-0.0180*
R^2	96.10	97.40	95.40	92.60	97.80	99.10
R^2_{adj}	89.20	92.70	87.10	91.30	93.70	97.40
Lack-of-fit	NS	NS	NS	NS	NS	NS

[a] $Y = \beta_o + \beta_1 A + \beta_2 B + \beta_3 C + \beta_{11} A^2 + \beta_{22} B^2 + \beta_{33} C^2 + \beta_{12} AB + \beta_{13} AC + \beta_{23} CB$; A = Barrel temperature, B = Feed Moisture content, C = feed blend composition, * and ** = significant at 5% and 1% level of probability respectively.

3.4 Multivariate process optimization for proximate and mineral compositions

In this study, the intention was to develop a product which would have optimum nutrient composition that will satisfy nutritional requirement of young and adults as breakfast cereals. Results in Tables 3 and 4 were fitted into Minitab-16 software optimizer to locate optimum process conditions. To achieve the set goals, all the independent variables were kept in their selected ranges, while protein, fibre and calorie values and Fe and Ca were all set a goal for maximization (Table 7) (Park *et al.*, 1993. The results indicated that the optimum barrel temperature, feed moisture level and BGN composition were 120°C, 20% and 22.4g BGN per 100g broken rice. Optimum protein, fibre and calorie values were 21.66%, 1.34% and 394.33kcal/100g sample. For Fe and Ca content of the extrudates, optimum values under the process condition studied are 12.12mg/100g and 25.81mg/100g sample respectively (Table 7) at an overall desirability function of 0.9102.

Table 7: Constraints and goals applied to derive optimum conditions of processing parameters and responses for rice-bambara groundnut based extrudates

Variables	Goal	Upper limit	Lower limit	Importance	Optimum level
Independent variables					
A (^{o}C)	In range	100	140	3	120.00
B (g/100g sample)	In range	8	24	3	20.00
C (g/100g sample)	In range	15	25	3	22.40
Proximate composition (%)					
MC	Minimize	0.09	1.30	3	0.89
FC	Minimize	0.21	0.85	3	0.73
PT	Maximize	16.15	27.36	5	21.66
AC	Minimize	0.16	1.40	3	0.89
FB	Maximize	0.73	1.77	5	1.34
CHO	Minimize	69.50	81.57	3	77.81
CAL (kcal/100g)	Maximize	391.14	397.99	3	394.33
Mineral composition (mg/100g)					
Mg	In range	10.13	15.06	3	13.82
Mn	In range	4.02	7.33	3	5.14
Fe	Maximize	9.06	14.26	5	12.12
Cu	In range	2.12	5.14	3	3.67
Zn	In range	4.06	6.28	3	5.13
Ca	Maximize	23.04	33.03	3	25.81

3. Conclusion

Individual and combined effects of three selected extrusion cooking parameters (barrel temperature, feed initial moisture content and rice-bambara ground blend ratio) on the proximate and mineral compositions of extruded complementary foods were studied using CCRD model of RSM and desirability function. Applying numerical optimization techniques and method of desirability functions, optimization of barrel temperature (100-140oC), feed initial moisture content (15-25%) and feed rice-bambara groundnut ratio, the optimum extrusion conditions located are 120^{o}C barrel temperature, 20.0% feed moisture level and 22.4% feed bambara groundnut composition. Under these conditions, the optimum protein, calorie, Fe and Ca composition of the extruded foods are 21.66%, 394.33 kcal/100g, 12.12 mg/100g and 25.81 mg/100g respectively. The fitted regression models representing the relationship between the dependent and independent variables are very adequate to represent the relationship in their natural conditions based on the ANOVA test and regression analysis. The optimum protein, energy and mineral compositions are within the recommended values for normal growth and development for all age brackets and therefore could be recommended for mitigating protein-energy mitigation. The robust models developed for predicting the optimal production conditions are therefore suitable for the industrial production of rice-bambara groundnut based extruded foods.

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